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CHARACTERISTICS OF FLOW PAST FUSELAGES
AND WING-FUSELAGE SYSTEMS OF GLIDERS

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16. Abstract The paper contains the results of visualization tests and measurements of the velocity field of diffuser regions (with positive pressure gradient) on fuselages and fuselage transi- tion zones. Wind tunnel and flight tests on gliders were per- formed. Secondary flow phenomena influencing accelerated separ- ation and the influence of the geometry of wing-fuselage systems are discussed on the basis of various types of secondary flows. Various types of flow separation in the region of wings near the fuselage are shown in photographs. The principle of correct design of fuselages and wing fuselage transition zones is dis- cussed, the objective being to minimize the harmful effects of the secondary flows on the separation process.			
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CHARACTERISTICS OF FLOW PAST FUSELAGES
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Jerzy Ostrowski, Mieczyslaw Litwinczyk and Lukasz Turkowski

Besides aerodynamic properties of wings determined by their geometry and the aerodynamic characteristics of an airfoil, the design of the fuselage and the wing-fuselage transition region have a real effect on the flight characteristics of a glider.

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In the development of fuselage geometry, we may distinguish three time periods: (Fig. 1) [2] the first comprising designs borrowed direct-

ly from airplane design (pilot in sitting position), the second, inaugurated toward the end of the 1950's and applied in Polish designs, (pilot in prone position) which allowed to reduce considerably the front surface of the fuselage and provided greater possibilities of laminarizing flow around the front of the fuselage. The third time period covered the production, in the late sixties of "tadpole" fuselages whose shape was selected in such a way that a slight increase in eddy-making resistance reduced considerably skin friction drag which is essential at high velocities (at small angles of attack). Moreover, such a fuselage can have smaller eddy-making resistance during flight at great angles of attack which is important for gliders that have no equipment for increasing aerodynamic

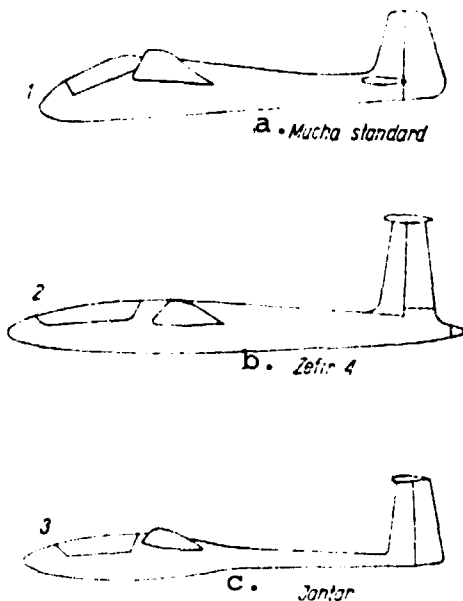


Fig. 1

Key: a. Standard mucha (fly)
b. Zephyr 4
c. Yantar

*Numbers in the margin indicate pagination in the foreign text.

lift (greater range of fuselage deflections).

Designing the fuselage in the shape of a tadpole gave rise in the rear of the cockpit to a region with a great positive pressure gradient, in which, because of the three dimensional character of the flow around the cockpit (asymmetry resulted from shape and arrangement), the flow took on a different form than in a case of an axially symmetrical body. In addition, design considerations made it necessary to attach the wings at this diffuser part of the cockpit which increased diffuser effects during flow past wing sections near the fuselage and thus increased the intensity of secondary flows and accelerated flow separation.

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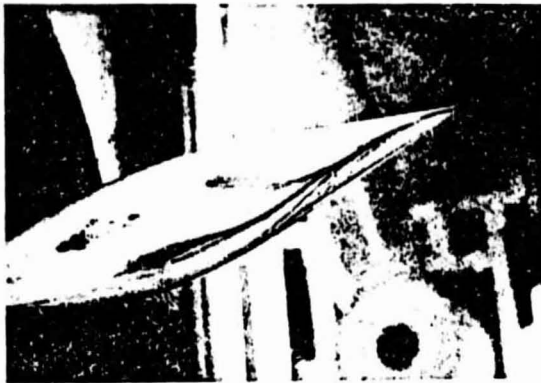


Fig. 2



Fig. 3

In order to investigate these phenomena and elaborate principles for proper design of fuselages and wing-fuselage transition zones, we undertook, at the request of and in collaboration with the Center for Glider Research and Development, studies which involved measurement and simulation of models in a wind tunnel and flight tests of various types of gliders.¹

A properly designed tadpole fuselage should ensure, in the range of useful angles of attack, the best possible laminarization of the flow around the front (convergent) section of the cockpit, flow without separation in the section without the diffuser as well as formation flow with the smallest possible parameter gradients in the transition zone.

¹ Witold Skurski and Marek Tarczynski, students at the Department of Mechanical Engineering and Aeronautics Institute of Technology, took part in the wind tunnel tests; Stanislaw Skrzynski, Tadeusz Dunowski and students at the Scientific Training Centers of the Pilot's Circle at Bielsk-Biala in 1974 and Leszno in 1975 took part in the flight tests.

Despite real limitations on changes in shape imposed by operation and design considerations, considerable freedom is available to the designer. Tests aiming to optimize the shape for a specific type of glider would require an investigation of many designs and very laborious measurement on expensive models because of the necessity of testing in the range of high Reynolds numbers.

The situation is alleviated by the fact that the design has an optimum which is relatively flat in the range of the investigated parameter changes and that a number of design principles can be ascertained beforehand on the basis of relatively simple measurements.

Laminarization of flow around the cockpit requires, for example, in /93 addition to surface smoothness, that the shape of the cockpit ensure laminar layer stability, i.e. great curvatures of the contour both in longitudinal sections and cross sections and proper selection of the radius of the nose of the fuselage. The smaller the range of angles of attack of the fuselage, the smaller the radius of the nose. The maximum length of the front section is determined by design considerations (pilot height).

The criterion for designing the rear section of the cockpit, from the standpoint of flow past the fuselage itself, reduces to forcing in this zone flow without separation, which is easily achieved by proper selection of the diameter of the beam connecting the cockpit and control surfaces. However, forcing the proper flow in the wing-fuselage transition zone remains a difficult problem which must be solved to obtain the correct design and greatest attention has been given to an investigation of a particular phenomenon in this zone.

For wind tunnel tests (to increase the Re number), we used a model of the cockpit properly designed to ensure flow without separation in the diffuser region. Flow around the cockpit was visualized and flow formation in the diffuser region was investigated for various angles of attack. Figs. 2 and 3 show flow around the cockpit at angles of attack $\alpha = 5^\circ$ and $\alpha = 15^\circ$.

In both cases, one can observe on the model surface marked drifting of the layer toward the back of the cockpit in the diffuser region. This drift becomes stronger with increasing angles of attack.

To evaluate the quantitative effect, velocity measurements were made in the diffuser region. The results of these measurements are presented in Figs. 4 and 5. These figures illustrate with the aid of constant velocity lines, the increase in the thickness of the layer and two distinct symmetric vortices arising as a result of curling of the vortex sheet flowing off the lateral surface. /94

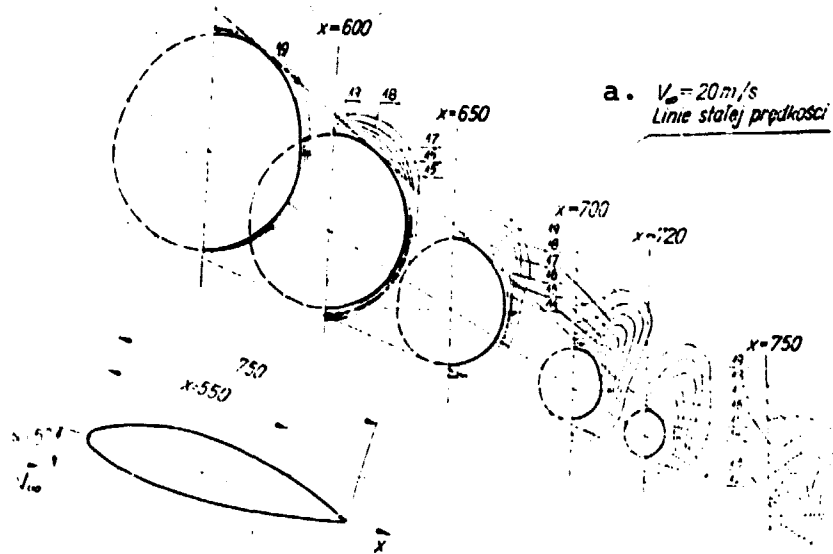


Fig. 4

Key: a. Lines of constant velocity

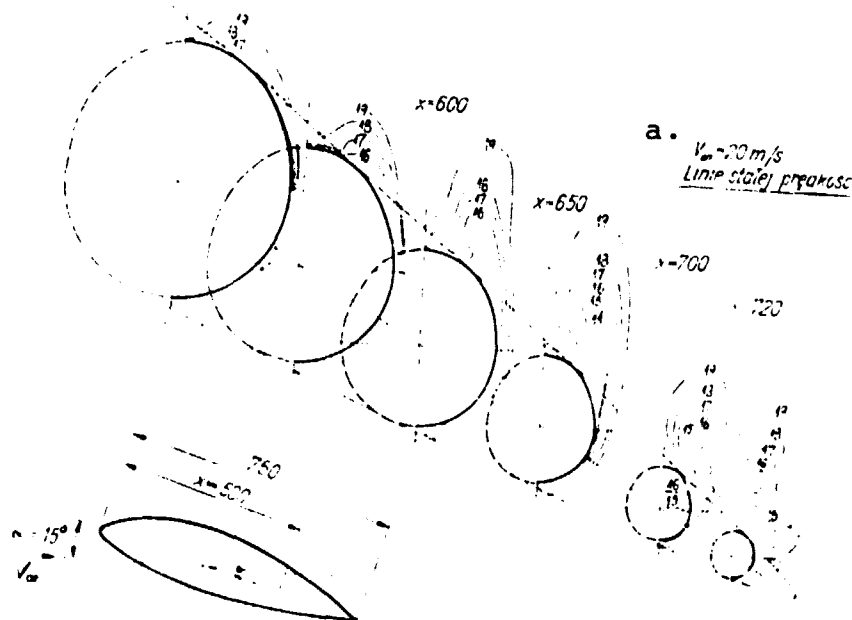


Fig. 5

Key: a. Lines of constant velocity

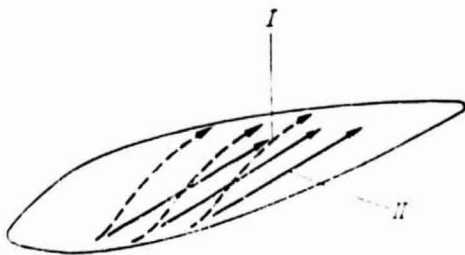


Fig. 6

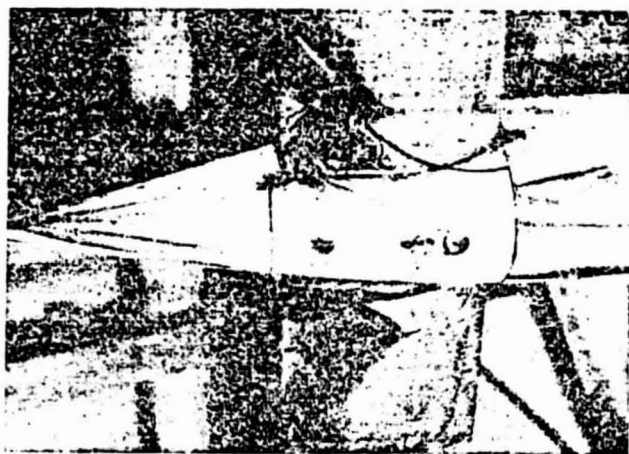


Fig. 7

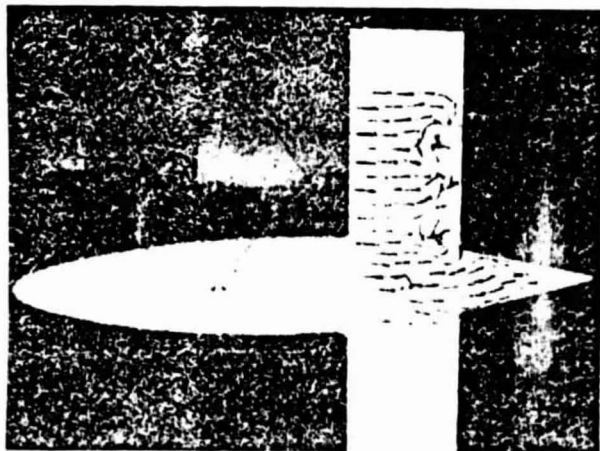


Fig. 8

This vortex sheet is formed in a /95 region in which distinct variations in velocities and in the direction of velocities occur in the boundary layer (Fig. 6). In the figure, the dashed lines indicate the directions of flow near the boundary and the solid lines, the directions of flow in the upper part of the layer. The effect resulting from the formation of such vortices is a distinct decrease in that region, thickening of the wake and increased loss of momentum which leads to increased drag.

Fastening wing sections to the fuselage improved flow around the cockpit proper. The wing cut through the vortex sheet drift region and forced a change in the direction of flow around the cockpit in the diffuser region. On the other hand, we noted the adverse effect of the pressure differences on adjacent fuselage and wing surfaces. As a result of the greater pressures that are predominant in the diffuser region of the cockpit, the boundary layer drifts from the fuselage to the wing causing premature separation of flow from the wing surface (Fig. 7). seen more clearly by visualization of flow using threads (Fig. 8).

The influence of the angle of attack of the model on the flow part of the transition zone is illustrated in Figs. 9 and 10 where the solid lines connect points of identical velocity. The diagrams obtained in this manner in individual sections illustrate increasing turbulence in the transition zone. A comparison of the diagrams shows a distinct increase of the turbulence regions and a distinct decrease in the velocity of the flow increasing angle of attack. /96

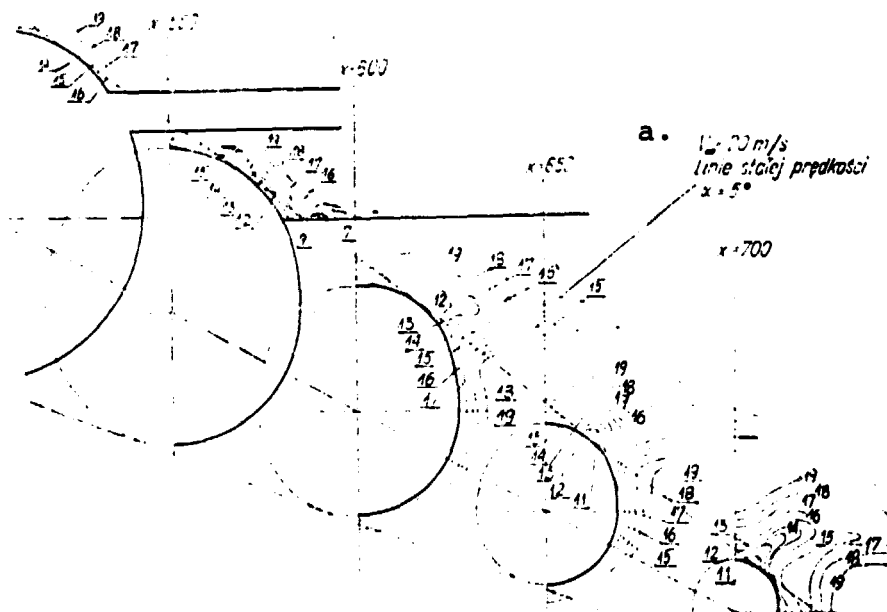


Fig. 9

Key: a. Lines of constant velocity

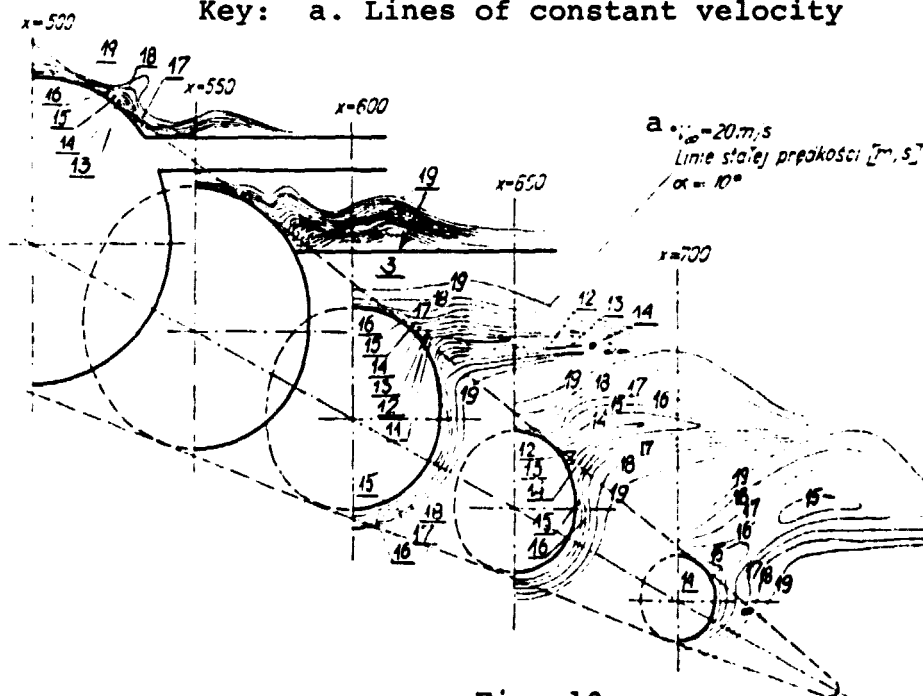


Fig. 10

Key: a. Lines of constant velocity

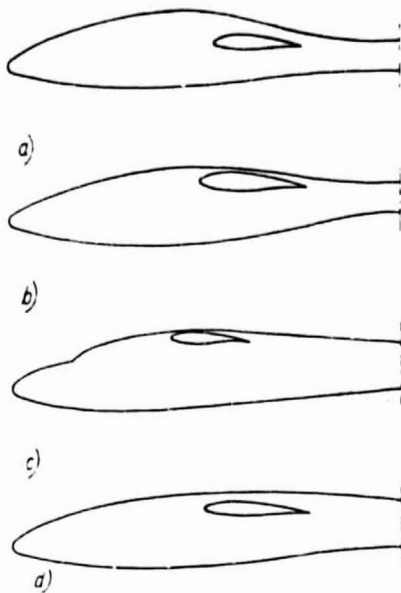


Fig. 11



Fig. 12

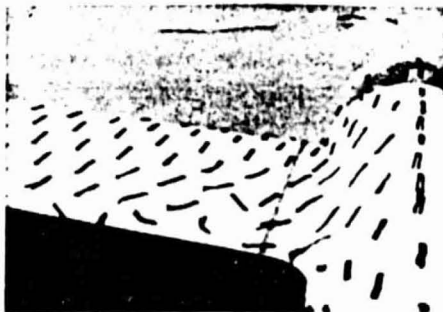


Fig. 13

The presented results of wind tunnel tests show clearly the diffuser-shaped design adverse effects of the cockpit at the place where the wings are attached. Because of lack of opportunity to make measurements in the range of corresponding large Re numbers on a glider model with wings having the proper span, we were not able to obtain quantitative results. [The entire sentence missing from original. Translation is sheer guess.] We

therefore performed tests in flight on a dozen gliders or so of different types where inflight visualization was carried out for flow past the diffuser section of the cockpit and the transition zone. Using threads we also obtained images of the flow past them at various velocities. In several cases, we measured dynamic pressures in the section behind the wing and plotted diagrams depicting the changes in the velocity field in the investigated region. Measurements were made with the aid of rotating combs assembled from tubes used for measurement of static and total pressure.

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Analysis of the results of measurements and visualization of various systems allowed the evaluation of the effect of the geometry of these systems on flow phenomena and thus to draw conclusions about the choice of the shape of

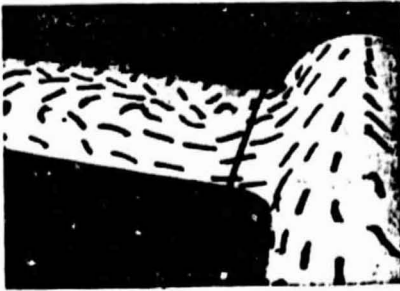


Fig. 14

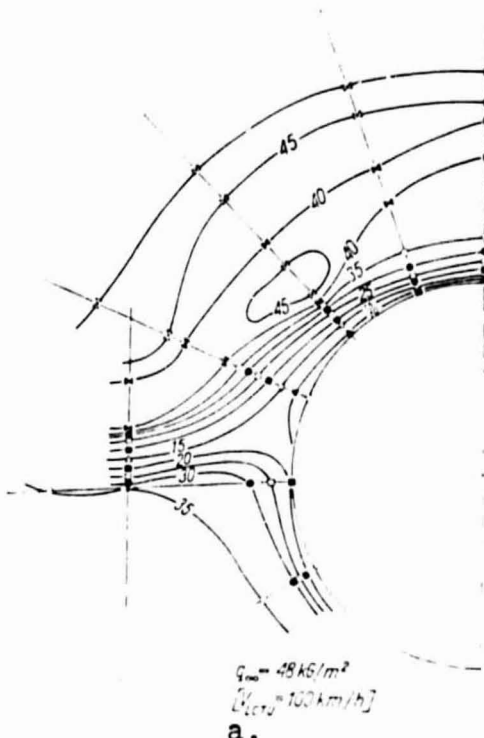


Fig. 15

Key: a. Flight

the fuselage and the wing-fuselage transition zone in a manner ensuring proper flow past this zone.

Without presenting all of our materials, we will limit ourselves in this article to a discussion of characteristic cases of flow past the zone under consideration. Figure 11 presents designs of the shape of the fuselage discussed below. Design "a" is characterized by great elevation of the cockpit, the wing is situated in the distinctly formed diffuser zone of the cockpit at about two-thirds of its entire height at the place where the wing is attached, and wing loading was 310 N/m^2 . This version corresponds to that tested in the wind tunnel which was discussed above. Flow past the transition zone for this case is illustrated in Figs. 12, 13 and 14, which show buildup of the separation with decreasing velocity. Distinct formation of the drift of the flow from the fuselage to the wing can be seen in Fig. 12. It has already been pointed out that drifting of the layer is caused by flow separation. It can be seen from Fig. 14 that as

a result of different directions of drift [missing sentence in copy of original text] causing repeated growth of the separation zone and its rise, which most certainly reduced aerodynamic lift and increases glider drag.

Figs. 15, 16 and 17 show the build up of the separation zone. The figures show the increase in the thickness of the boundary layer in the zone near the fuselage and dead zones at the inception of the separation process. (Fig. 17 corresponds to Fig. 14.)

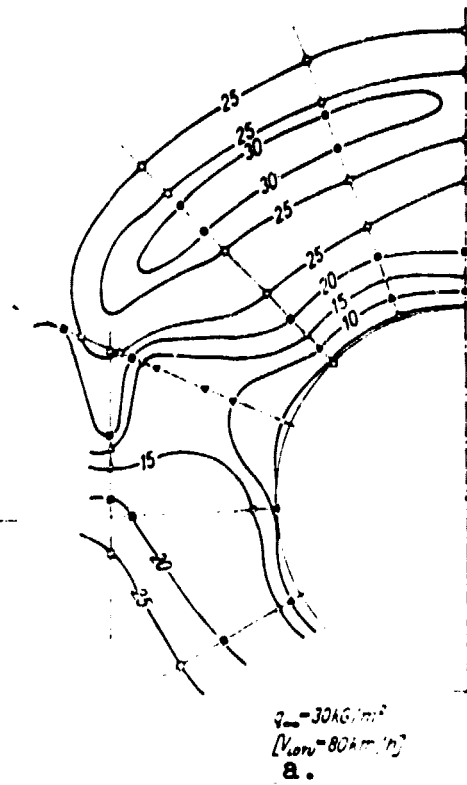


Fig. 16
Key: a. Flight

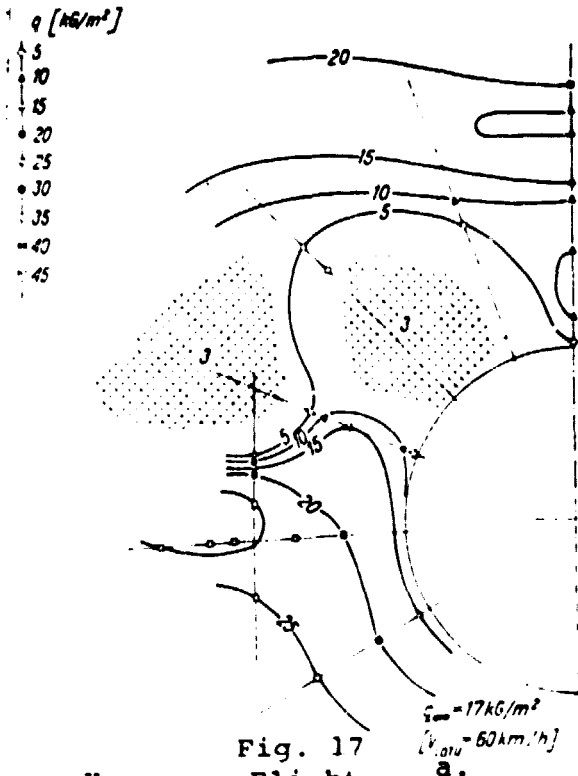


Fig. 17
Key: a. Flight

A factor slowing down propagation of the process is the drift of the layer from the outer wing into the interior of the separation zone which is formed as a result of the increase of subatmospheric responses in this zone. In the discussed case, this factor does not play an essential part because of the pronounced predominance of drifting from the cockpit to the wing.

Figure 18 presents a diagram illustrating in general the phenomena in question. The arrows indicate the directions of drift of the flow and the direction of flow of the outer stream. Fig. 18b clarifies the phenomenon of drift of the layer from the outer wing to the separation zone. It can be seen that this drift arises as a result of pressure differences caused by separation -- compare curve "a" representing the pressure distribution in the separation zone (section a-a) with curve "b" representing the pressure distribution in section b-b outside this zone.

In order to reduce the adverse effects of drift of the flow, we used several kinds of flaps that forced reattachment of the layer. Figs. 19 and 20 show one of the test versions. [Sentence missing the the original copy.] It can be seen from a comparison of Figs. 13 and 20 that a visible improvement has been achieved

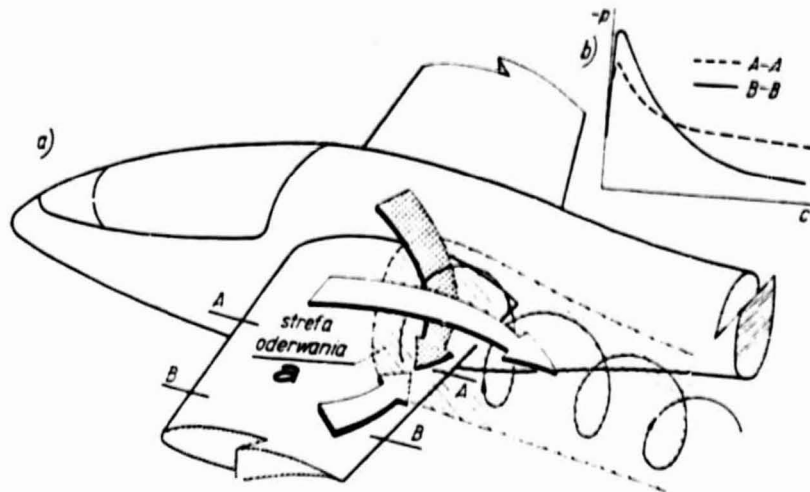


Fig. 18

Key: a. Separation zone

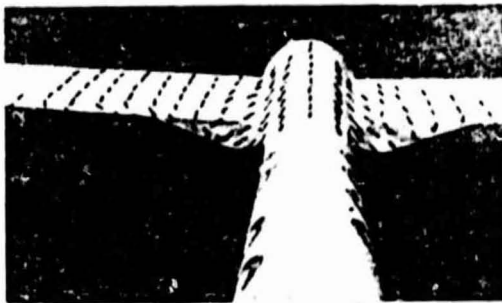


Fig. 19

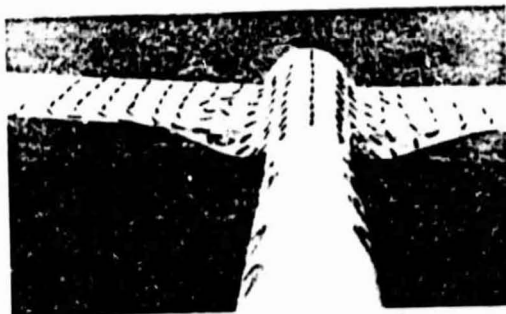


Fig. 20



Fig. 21

(measurements taken under identical conditions). The separation zone has been reduced and a vortex is no longer formed. As a result of the increasing subatmospheric pressures in the section of the wing on which drift occurs due to the presence of the flap, the rate of the oncoming airflow from the outer wing increases, especially near the trailing edge (compare Figures 19 and 12). It can also be seen that the rate of drift from the fuselage to wing is smaller.

Thus the use of a flap brought about compensation of the effects of drift of the flow from the fuselage and the outer wing to the transition zone. The properties of the discussed glider at great angles of attack were improved in this manner. It has been established that application of this kind of flap has a negligible effect on the characteristics of a glider in the range of high velocities.

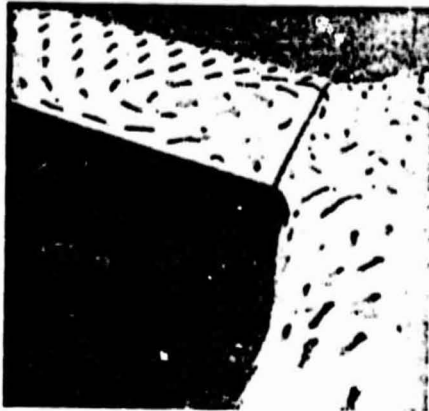


Fig. 22

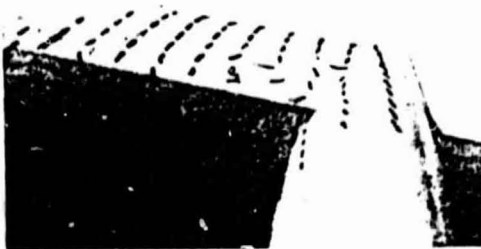


Fig. 23



Fig. 24

Design "b" (Figure 11) represents the case when there is no drift of flow from the fuselage to the wing and the dominant role in the formation of the separation zone is played by drift of the flow from the wing. This design is characterized by a weaker diffuser effect (gentler decrease of cross section) of the cockpit in the vicinity of the spot attached. Wing loading was 306 N/m^2 . The course of separation is illustrated in Figures 21 and 22. It can be seen that separation first encompasses the rear of the cockpit. Increasing subatmospheric pressures in the separation zone cause drifting from the outer wing surface to the interior of this zone and, in effect, as the angle of attack increases, we observe the phenomenon of reversed circulation vortex formation (with respect to the previously discussed flow) (case "a"). [Sentence missing in copy of original text.] Separation of the layer from the fuselage surface is accelerated in this case by the exceedingly high placement of the wing as a result of which a diffuser pocket is formed in the region where the lower surface of the wing penetrates the lateral surface of the fuselage. The presence of such a "pocket" causes a decrease in velocity

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and an increase in pressure on the lower wing surface at the trailing edge which in turn substantially increased the $c_{l \text{ max}}$ of the wing sections near the fuselage. An additional adverse factor visualized in this design is the effect of the drift of the layer from the lateral surface of the fuselage upward in the sections behind the wing (Figure 3 compared with Figure 21). Both of these factors in effect decrease stability in the diffuser section of the fuselage which in turn leads to rapid separation on the fuselage and in the region of the wing near the fuselage. As a result of this drifting of the layer from the outer wing

develops with increasing angle of attack, leading to formation of a built up separation region with strong eddy motions in this zone.

The adverse effect of the "pocket" discussed above is illustrated by the design with a classical fuselage and wing (Figure 11, case "c"). Wing loading for this glider was 260 N/m^2 . Figures 23 and 24 show the buildup of separation from wing sections near the fuselage in the "pocket" region. Separation begins at an instant when flow is still stable in the adjacent sections (located farther away from the fuselage). This case is a good illustration of the decrease in the maximum lift coefficient in the region of influence of the "pocket."

A case in which the design of the shape of the transition zone was /103 selected appropriately is illustrated by version "d" in Figure 11. This

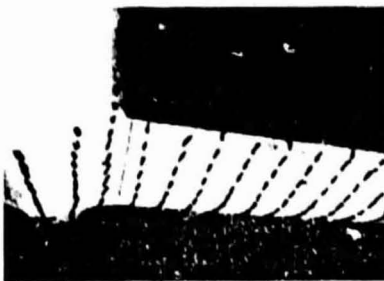


Fig. 25

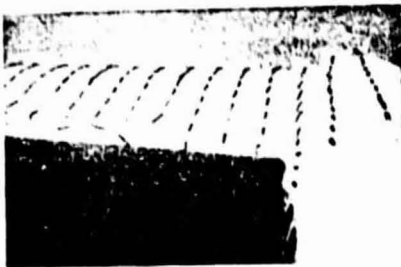


Fig. 26



Fig. 27

is depicted in Figures 25, 26 and 27. It can be seen that separation begins at a certain distance from the fuselage, in the range of velocities at which no disturbances are observed in the [words missing from the original; translation is guess] wing-fuselage transition zone to the wing without formation, a vortex in the separation region that causes buildup of this region and thereby increases drag. It can be seen from Figure 11d that the wing is located in the fuselage region with a weak diffuser effect. Wing surface loading in this case was 300 N/m^2 .

The phenomena discussed above and the presented examples indicate the need for changing the shape of fuselages and the wing-fuselage transition zone. Tadpole-shaped fuselages, despite their unquestionable advantages, require further modification, especially for standard class gliders from the standpoint of improved flow past the transition zone.

Proper formation of this zone requires a longer cabin and placement of wings in the sections of the fuselage which is not diffuser-shaped. The diffuser effect can be reduced in the upper section by an "under-cutting" of the lower section and mounting high the beam connecting cockpit and tailplane.

An increase in the diffuser in the bottom sections of the cockpit does not have such a great effect on fuselage drag, since the effect discussed -- drift of the layer -- has a stabilizing influence on the flow past this section. Here, however, attention must be given for designing the cockpit, particularly its bottom, in a way which will not cause at a wide wing setting, stronger drifting of the boundary layer to the bottom of the cockpit at flight velocities.

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